Spotlight on
Intensity Modulated Radiotherapy

Perspectives on:
physics and engineering in medicine and biology

Shaping the future of cancer treatment
High energy radiation is one of the most effective ways of treating malignant tumours. X-rays, beams of electrons, and even particles such as protons and heavy ions, damage living cells, and in the case of cancer cells eventually kill them if the dose is high enough. Fifty per cent of cancer patients receiving radiotherapy are cured, while the quality of life of the remainder is invariably improved.

Since the discovery of X-rays in 1895, there has been a great deal of research into the most effective methods of delivering the radiation. During the past decade a new development called intensity modulated radiotherapy (IMRT) has been making a significant impact in the management and cure of cancer, allowing more challenging tumours to be treated.

The principle is to ‘sculpt’, or modulate the radiation field over space so that its shape matches that of the target tumour (including any concavities in its surface) while variations in its intensity deliver the optimal dose. In this way, the therapy avoids irradiating normal tissue especially nearby critical organs, and can dispense a higher, and thus more effective, radiation dose than would otherwise be possible. Examples of cancers successfully treated include those of the prostate gland which is usually wrapped around the rectum and bladder, and of the head and neck - avoiding the spinal cord, optic nerve or salivary glands (radiation damage to the parotid glands controlling the flow of saliva causes considerable distress). American studies have shown that IMRT can deliver up to 25 per cent higher dose to prostate tumours, for example, doubling efficacy to 90 per cent, while reducing complications in normal tissue from 10 to 2 per cent.

Although this ‘conformal’ approach to radiotherapy is by no means new, it is only in recent years that the technology has been available to develop practical, automated methods of implementation. This is thanks to advances in 3D imaging, sophisticated planning software and clever, computer-controlled mechanical devices to shape the X-ray beam - all developed by physicists working alongside oncologists and radiologists.

How does IMRT work?

The X-rays (or electrons) are produced by a linear accelerator (linac) which can rotate around the patient who lies on a movable couch. The beam can therefore access the target site from many angles. Traditionally, the contours of the radiation beam are controlled via a pair of lead jaws. The intensity might be varied to some extent using a couple of metal ‘compensators’ of a particular thickness designed for a specific treatment; breast cancer is treated with just two beams in this way. However, to deal with the kinds of tumour mentioned earlier needs a complex radiation field built up of many small beams. This can be achieved using a device called a multileaf collimator (MLC). This consists of up to 120 pairs of finger-shaped iron or tungsten leaves which can separately move across the beam path to intercept the radiation and thus control its flow to a particular spot - rather like periodically blocking groups of pores in a shower head to get a particular intensity and shape in the water flow.

There are two ways of controlling the leaves: either by positioning them statically to integrate the radiation dose in steps - the ‘step-and-shoot’ method; or by moving the leaf pairs under computer control so they
sweep out the required dose profile with the radiation continually on. The jury is out on whether the static or dynamic approach is better but practitioners agree that both work well, and some feel an intermediate variation may, indeed, be the solution. In the UK, companies Varian, Elekta and Siemens offer these systems.

Of crucial importance is the planning and preparation before treatment. First, the tumour and surrounding areas are imaged, usually using computerised tomography (CT). This method of taking X-ray images in ‘slices’ across the body can reveal the 3D shape of a tumour with millimetre precision. Other well-established imaging techniques such as magnetic resonance imaging (MRI) and positron emission tomography (PET) can also be used. These are all techniques developed by physicists.

The 3D image is then used first to calculate the precise dose distribution needed to treat the tumour and then to program the MLC to give the correct sequence of leaf positions. The latter task has involved developing algorithms optimised by any of several mathematical methods (such as simulated annealing). The next job is to check that the delivered dose is equal to that assumed and required to treat the disease effectively. This is done by testing the procedure on a ‘phantom’ - a material object which mimics the patient and can contain various sensing devices.

Several other approaches to intensity modulation are also being developed. One promising technique, tomotherapy, based on the same principle as CT, uses a fan-shaped beam rotating around the patient as the patient moves longitudinally through the beam. This creates a helical field which is then modulated by computer-controlled tungsten ‘vanes’ passing across it. Other methods include using one-dimensional static beams delivered via multiple rotations, or ‘painting’ the target by scanning with a single, modulated pencil beam. In the future, robotic linacs with online imaging may offer the ultimate in rapid dose control, especially taking account of interfering movements of the patient. These approaches are examples of purposely designed IMRT systems that are becoming available on the market.

While IMRT is becoming routine in some clinics in the US, it is still not yet widely available in the UK. Nevertheless there is considerable clinical activity in several of the UK’s major medical centres. For example, the Royal Marsden NHS Trust has carried out successful trials treating breast and prostate cancer, while the Christie Hospital in Manchester have been treating patients with bladder and prostate cancer. It is also close to implementing techniques for breast and cervical cancer and for soft-tissue sarcomas, as well as working on techniques for some head and neck treatments, and for oesophageal cancer. A medical team at the Princess Royal Hospital, Hull reports success in treating head and neck cancers, and lung disease where the tumour lies close to the spine. The team is also running a ‘dose escalation trial’ aiming to increase the dose to inoperable pancreatic cancers.

We are likely to see IMRT become a standard treatment in the next two or three years. IMRT specialists agree that the therapy should be made available widely, when deemed the most appropriate treatment. However, it is important to note that the UK is desperately short of specialists trained in this burgeoning area which offers exciting opportunities for young physicists.
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Institute of Physics and Engineering in Medicine
Fairmount House
230 Tadcaster Road
York YO24 1ES
United Kingdom

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Enquiries:
Tel: +44 (0)1904 610821
Fax: +44 (0)1904 612279
office@ipem.ac.uk
www.ipem.ac.uk